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Estimating Cybersickness of Simulated Motion Using the Simulator Sickness Questionnaire (SSQ): A Controlled Study

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***Abstract*—The aim of this experiment was to determine which cybersickness symptoms are associated with simulated motion, by comparing responses to the Simulated Sickness Questionnaire (SSQ) between a control and experimental condition. Using non-parametric statistical tests, we found that general discomfort, fatigue, headache, eyestrain, difficulty in focusing eyes, increased sweating, nausea, difficulty in concentrating, stomach awareness and blurred vision were significantly higher in a high simulated motion task compared with a low simulated task. The implications for preventing cybersickness in virtual environments are discussed.**

Keywords-Simulator Sickness Questionnaire; cybersickness

I. INTRODUCTION

Virtual reality environments (VREs) provide innovative tools for research, professional training and recreational pursuits. VREs are expected to be widely deployed in coming years, as cost barriers to entry are reduced. However, in an era of legislated duty of care, and potential liabilities to employees, patients, students and consumers, VREs must be demonstrated to have safe operating limits. In particular, previous research on motion sickness symptoms arising in response to the use of virtual environments [1][2][3] has created health and safety concerns. Many of these symptoms are associated with perceived motion in a VRE, even when there is no physical motion of the subject who experiences these sensations. While there are competing theoretical explanations of why these cybersickness symptoms occur, our purpose in conducting research on these symptoms is to determine which symptoms can be attributed to being in a VRE versus being in a VRE with simulated motion. Unfortunately, a lot of research into cybersickness – even with quite sophisticated experimental designs – has lacked the rigor of a control condition to ensure that variance associated with simulated motion can be correctly attributed to a cause.

Previous research has found that a twenty minute exposure to VREs can increase cybersickness symptoms in over 60% of participants [4]. Sharples [3] investigated virtual reality induced symptoms and effects and reported 60 to 70% of participants described increases in pre- and post-virtual reality exposure on a range of display conditions. The symptoms associated with computer-generated environments are similar to those experienced when exposed to real movement, such as that felt when on a rocking boat, where there is visual and vestibular stimulation. In computer-generated VREs, there is no vestibular stimulation. The collective set of symptoms associated with the perception of motion when no physical motion exists is known as cybersickness [2] or Visually Induced Motion Sickness [1].

A standard questionnaire, the Simulator Sickness Questionnaire (SSQ) [5], has been developed to determine whether users of VREs experience cybersickness symptoms. Using the SSQ, previous studies have shown that exposure to simulated motion in a VRE produces mild to severe cybersickness symptoms in between approximately 50 to 80% of participants [2]. Other studies have attempted to relate characteristic changes in the physiology of cybersickness with user responses on the SSQ, finding strong correlations between some self-report and physiological measures [2]. Since physiological measures are usually invasive and time-consuming, the results of Kim [2] indicate that the SSQ alone may be sufficient to determine whether a user is suffering cybersickness, since the SSQ uses a relatively straightforward scoring approach [5]. Quantifying simulator sickness symptoms should be a functional measure of the severity of the symptoms an individual experiences and reports [5].

One weakness in both the Kim [2] and the Kennedy [5] studies is the absence of a baseline against which variance in responses on the 16 symptom variables of the SSQ can be attributed to simulated motion, as opposed to (say) just being inside a VRE. The identification of a baseline against which symptoms can be evaluated under different types of simulated motion is both valuable and necessary if (a) the self-report measures can properly be associated with simulated motion, and (b) useful for further understanding the theoretical underpinnings of simulated motion sickness, especially given the high correlation between physiological and self-report measures.

A crucial feature of an experimental design is a control condition against which an experimental condition can be evaluated. We propose to measure changes in simulator sickness severity scores between a control and an

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experimental condition. While there are a number of potential control conditions, we have chosen to evaluate self-report responses between immersion in a VRE with low simulated motion compared to a high simulated motion condition. Thus, we assert that we can partition the variance due to being in a VRE alone, versus a VRE + simulated motion. Other psychological conditions – such as anxiety – have been shown to significantly increase when simulated motion increases [7].

In this study, we report the results of an experiment using the SSQ, to determine the effects of simulated motion on self-reports of cybersickness. Since all of the 16 measures in the SSQ have previously been associated with cybersickness, we predict that there will be significant increases in all cybersickness symptoms between the control and experimental conditions.

II. METHOD

A. Participants

Twenty eight (10 female, 18 male) participants ranging in age from 18 – 30 years old participated in the experiment. All participants were student volunteers from Macquarie University. All were healthy, as determined by a Health Questionnaire and had normal or corrected to normal vision. Participants were naïve to virtual immersive environments. Only participants who had no illnesses were accepted.

Prior to the experiment a package was emailed to the student containing the Macquarie University Ethics Committee approved consent form, a health questionnaire and a comprehensive letter informing them not to eat or drink anything two hours prior to the experiment and not to consume illicit drugs or caffeine for 12 hours prior to the experiment.

The consent form detailed the specific purpose of the experiment was to investigate motion sickness and explained their rights to discontinue the experiment at any time. All participants were fluent in spoken and written English as determined by their enrolment in a degree program. No participant had been exposed to the virtual reality environment prior to the experimental session. The study complied with the Macquarie University Ethics Committee Approval.

Written informed consent was obtained prior to the experiment.

B. Experimental Protocol

Participants were tested individually in a repeated measures design, where the participants acted as their own control. Prior experience remained constant over the entire experiment thereby maximizing sensitivity to the independent variable, since all participants were naïve to being exposed to the experimental virtual environments. Participants were seated in a chair placed centrally in front of the screen and instructed that they would be shown two six minute virtual reality environments and reminded that they could discontinue the experiment at any time during the course of the session. The experimenter verbally asked the participant "how are you feeling" during each condition of the experiment at 2 minutes and 4 minutes and participants orally answered.

Prior to the experiment participants completed an Anxiety Scale [2]. The Simulator Sickness Questionnaire [5], Post Immersion Malaise Scale [5] and the Anxiety Scale [2] were administered after both the control and experimental conditions.

C. Virtual Environments

Two virtual reality immersive environments were shown to the participants. The control condition consisted of gentle flight over snow covered gently rolling hills (Fig. 1). The experimental condition involved a virtual rollercoaster ride that travelled along winding, ascending and descending tracks and through rickety tunnels (Fig. 2).

Each immersive environment condition entailed a two minute continuous circuit which was played three times to give a six minute experience. The camera speed was constant at 20 metres per second in both the control and experimental conditions.

The apparatus comprised of a curved front projection 160° canvas screen (6.2m x 1.7m), three SEOS Cathode Ray Tube Projectors, Nuvision Stereo Shutter Goggles.

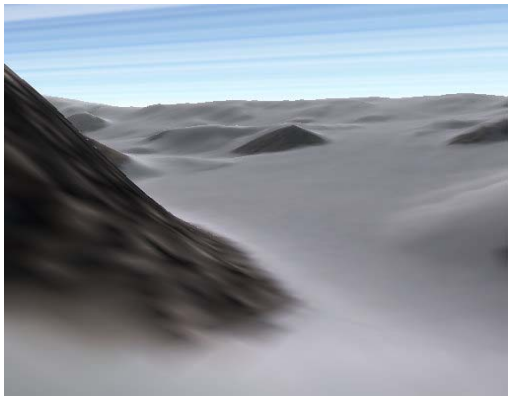

Figure 1. Control condition – snow scene

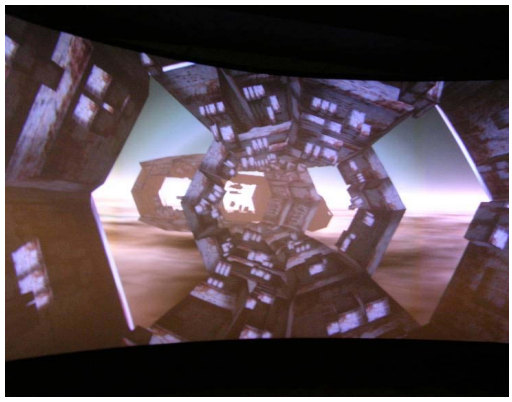

Figure 2. Experimental condition – rollercoaster

III. RESULTS

The results of the responses to the SSQ for post immersion in both the experimental and control conditions were analysed using the parametric matched samples *t*-test, and the non-parametric Wilcoxon Matched Pair Signed Rank Test. A non-parametric test was chosen since no assumptions were made about the normality of the distribution of the sample data, to confirm the results established by the parametric *t*-test. For all symptoms, there was complete agreement about the significance of results found.

The results for the Matched Samples *t*-test can be viewed in Table 1 and the Wilcoxon Matched Pair Signed Rank Test can be found in Table 2. Significant increases between the control and the experimental conditions were revealed for General Discomfort, Fatigue, Headache, Eyestrain, Difficulty in Focusing Eyes, Increased Sweating, Nausea, Difficulty in Concentrating, Stomach Awareness and Blurred Vision. No significant increases were observed for increased salivation, dizziness (eyes open or closed), vertigo, burping or fullness of head.

TABLE I. MATCHED SAMPLES T-TEST

Symptom	t-Test
General Discomfort *	t(27)=-3.31, p=0.003
Fatigue *	t(27)= -2.52, p=0.018
Headache *	t(27)= -2.27, p=0.031
Eyestrain *	t(27)= -3.95, p=0000
Difficulty focusing eyes *	t(27)= -2.93, p=0.007
Increased sweating *	t(27)= -2.92, p=0.007
Nausea *	t(27)= -3.60, p=0.001
Difficulty concentrating *	t(27)= -2.35, p=0.026
Stomach awareness *	t(27)= -3.61, p=0.001
Blurred vision *	t(27)= -2.55, p=0.017
Increased salivation	t(27)= 0.36, p=0.720
Dizziness Eyes Open	t(27)= -1.61, p=0.118
Dizziness Eyes Closed	t(27)= -1.53, p=0.136
Vertigo	t(27)= -1.80, p=0.083
Burping	t(27)= -.891, p=0.381
Fullness of head	t(27)= -1.76, p=0.090

* Significant value

TABLE II. WILCOXON MATCHED PAIR SIGNED RANK TEST

Symptom	Wilcoxon Test
General Discomfort *	z = -2.85, p=0.004
Fatigue *	z = -2.30, p=0.021
Headache *	z = -2.12, p=0.034
Eyestrain *	z = -3.20, p=0.001
Difficulty focusing eyes *	z = -2.56, p=0.01
Increased sweating *	z = -2.54, p=0.011
Nausea *	z = -2.98, p=0.003
Difficulty concentrating *	z = -2.17, p=0.029
Stomach awareness *	z = -3.02, p=0.002
Blurred vision *	z = -2.33, p=0.02
Increased salivation	z = -1.09, p=0.272
Dizziness Eyes Open	z = -1.51, p=0.130
Dizziness Eyes Closed	z = -1.50, p=0.132
Vertigo	z = -1.73, p=0.084
Burping	z = -0.95, p=0.339
Fullness of head	z = -1.70, p=0.088

*Significant value

IV. DISCUSSION

The results of this experiment indicate that self-report of 10/16 symptoms previously associated with cybersickness in a VRE significantly increase when simulated motion is increased, while 6/16 do not significantly increase. Since previous uncontrolled studies [2][5] had indicated that all 16 symptoms were associated with cybersickness, these results significantly enhance our aspect of perceived motion (eyestrain, difficulty focusing eyes, blurred vision), perceived nausea (nausea, stomach awareness, discomfort, fatigue) and cognitive (headache, difficulty concentrating). However, symptoms associated with gastric activity (salivation, burping) and vestibular activation (vertigo, dizziness) were absent. These results indicate that vection [8] rather than vestibular activation might be mediated through a cognitive route to generate the nausea symptoms. These results also accord with sensory conflict theory, since no actual vestibular activation is reported, and yet participants still feel nauseous [9].

Further research is required to determine the exact relationships between these groups of variables, and/or their internal (factor) structure. Ultimately, a computational that predicts the levels of nausea symptoms given a set of input conditions (cognitive, perceptual) should be developed to better understand the dynamics of cybersickness arising from simulated motion.

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